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DISCUSSION OF EFFECT OF ENTRANCE CONDITIONS ON DIFFUSER FLOW

(Published in July, 1952)

By Steponas Kolupaila, Arthur L. Collins, R. M. Olson, and J. M. Robertson and Donald Ross

HYDRAULICS DIVISION

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DISCUSSION

STEPONAS KOLUPAILA[4].—For the computation of the kinetic energy coefficient, the authors have developed a complicated formula (Eq. 6), based on the power law of velocity distribution, Eq. 5. Since, admittedly, the power-law velocity distribution does not fit measured velocity distributions too well, the writer suggests a direct procedure based on the integration of

$$\int^{A} u^3\, dA = 2\pi \int_0^{r} u^3\, x\, dx \quad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

or

$$\int^{A} u^3\, dA = \pi \int_0^{r^2} u^3\, d(x^2) \quad \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Eq. 9 is integrated by the planimetering of the area enclosed between the curve $u^3\, x$ and the diameter; and Eq. 10 is integrated by plotting u^3 against x^2 and measuring the area beneath the curve. Either integration is simple and gives satisfactory results, independently of the assumed law, even for an irregular velocity distribution across the diffuser.

ARTHUR L. COLLINS,[5] A. M. ASCE.—In the presentation of this subject the details of the measuring instruments for obtaining the data are as interesting as the mathematical conclusions.

Of particular interest is the determination of the velocity distribution at several cross sections by use of a cylindrical pitot tube (see under the heading, "Apparatus and Procedure: Test Facility"). No mention is made of the dimensions of the tube, nor how it was possible to take satisfactory readings near the tapered walls of the cone. The writer would also appreciate knowing the method of introducing the tube. Was this tube of the stub or through type?

A line drawing of the pipe layout and the pitot tube dimensions, submitted with sample data, would help to clarify these points.

R. M. OLSON[6].—In Minneapolis, Minn., studies of diffuser design and performance have been made at the St. Anthony Falls Hydraulic Laboratory. Fig. 2 indicates that the length of the transition between the straight pipe and the diffuser was about one pipe diameter for the 7.5° diffuser. The transition length for the other two divergence angles is not stated. Radial pressure gradients as well as longitudinal wall-pressure gradients in the transition region are both quite sensitive to changes in the length of this transition. The writer used a parabolic curve; but the difference between this curve and

NOTE.—This paper by J. M. Robertson and Donald Ross was published in July, 1952, as *Proceedings-Separate No. 141*. The numbering of footnotes, equations, and illustrations in this Separate is a continuation of the consecutive numbering used in the original paper.

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others is usually less than allowable machining tolerances. The effect of these variations on diffuser efficiency has not been studied systematically. The studies have been concerned primarily with the flow quality upstream from the diffuser, and, secondarily, with the diffuser performance. (Reports of these studies (31)[6a] (32) (33) (34) are available on interlibrary loan at the University of Minnesota Library, Minneapolis 14, Minn.)

The velocity profiles shown in Figs. 2, 7, and 8 are representative of diffusers with no obstructions in the entrance. This condition would exist for a venturi tube or for a bare water tunnel. However, experimental studies in water tunnels usually require the insertion of a test body and supports. The velocity profiles in the diffuser were quite dependent on the presence and location of even very small obstructions a short distance upstream from the diffuser. As an example, a faired probe, occupying less than 0.2% of the cross-sectional area of a 6-in. diameter test section, affected the flow in such a way as to change the core velocity at the end of the diffuser from 1.6 times the mean to less than the mean velocity when the probe was moved from the center to a point halfway to the wall. In each instance, the profiles were different from that for a bare diffuser entrance. No measurements of diffuser efficiency were made during any of these tests.

It is unfortunate that diffusers are rated on such different bases of efficiency. Hydraulic literature contains derivations and formulas for: (*a*) The energy-conversion efficiency, based on ideal pressure recovery from a one-dimensional analysis (this is the pressure (η_p) efficiency used by the authors); (*b*) the actual energy-conversion efficiency (η), based on ideal pressure recovery for the actual flow conditions; (*c*) the form-loss efficiency; and (*d*) the energy efficiency, as used by the authors. The first can be written as

$$\eta_p = \frac{C_p}{1 - \left(\frac{D_o}{D}\right)^4} \qquad (11)$$

and the second as

$$\eta = \frac{C_p}{\alpha_o - \alpha\left(\frac{D_o}{D}\right)^4} \qquad (12)$$

Eq. 12 seems to represent the pressure recovery efficiency more closely than Eq. 11 because it takes into account the change in velocity distribution. It would be of interest to know why the authors consider the second definition "* * * not suitable as a circuit parameter" (see the paragraph preceding "Summary").

At the St. Anthony Falls Hydraulic Laboratory, the measured efficiencies have been, consistently, about 3% less than those indicated in Fig. 6 and Table 4. This may be illustrated by citing tests conducted at R_o equal to 1×10^6 to 2.4×10^6, with a diffuser that had an area ratio of approximately 4, and angle of 6°40′, and a galvanized surface throughout most of its length. The acual entrance lengths were increased by one half an entrance diameter for the effect of the nozzle upstream, and by one half the length of the parabolic

[6a] Numerals in parentheses, thus: (31), refer to corresponding items in the Bibliography (see Appendix I of the paper and at the end of the discussion in this Separate).

transition to obtain the effective length. The measured pressure coefficients were also corrected to refer to the geometric beginning of the diffuser. Typical results are as follows:

β L/D_o	Measured pressure efficiency	Pressure efficiency from Fig. 6
7.7	0.91	0.94
19.8	0.89	0.925

Similar differences exist between the measured energy efficiencies and those indicated in Table 4. It is indicated in Fig. 3 that the differences in area ratio should not account for the differences in efficiency. Perhaps they are caused by a difference in diffuser wall roughness.

J. M. ROBERTSON,[7] M. ASCE, and DONALD ROSS.[8]—A specific study made for a certain design need was the basis for this paper on diffuser flow. From this study was extracted information of a basic nature which could be applied to similar problems; hence, the paper involved a compromise between the engineering and scientific approaches and is an attempt to condense a fifty-page report (28). The comments of the discussers are appreciated, as they indicate regions in which this condensation was excessive, in addition to supplementing the paper.

The pitot tube, about which Mr. Collins inquires, was a $\frac{1}{4}$-in. monel tube (0.028-in. wall) spanning the section, with an impact hole pointing upstream, and with the static pressure obtained from wall piezometers in the same plane as the front of the tube. With a small correction for the effect of the tube on the pressures at the wall piezometers, such a transverse pitot tube was found to give integrated discharges in excellent agreement with other flow measurements. Detailed checks with hypodermic-type pitot tubes showed the resultant velocity data to be satisfactory for the type of analysis presented in the paper, although not of sufficient precision for a detailed study of the velocity profiles near the walls. Fig. 7(*a*) shows the scatter in the data. It is not felt that any other presentation of sample data would be of value. Fig. 15 is a line drawing of one of the test setups, which indicates the locations of the piezometer and pitot-tube stations. Details of the experimental techniques including all measuring instruments were presented in another report (26).

The writers agree with Mr. Kolupaila as to the desirability of obtaining the kinetic-energy coefficient by direct integration rather than by substitution into a formula of doubtful validity. As a precise value of this factor was not necessary, and as Eq. 6 was quickly determined, engineering expediency prevailed over scientific thoroughness. The writers would like to point out, however, that the greatest error from use of the power profiles occurs near the walls. The profiles were nonetheless neither accurate nor symmetrical enough to warrant detailed integration.

Mr. Olson's discussion is welcome because it is based on a similar research study. The writers have studied the water tunnel investigations at the Univers-

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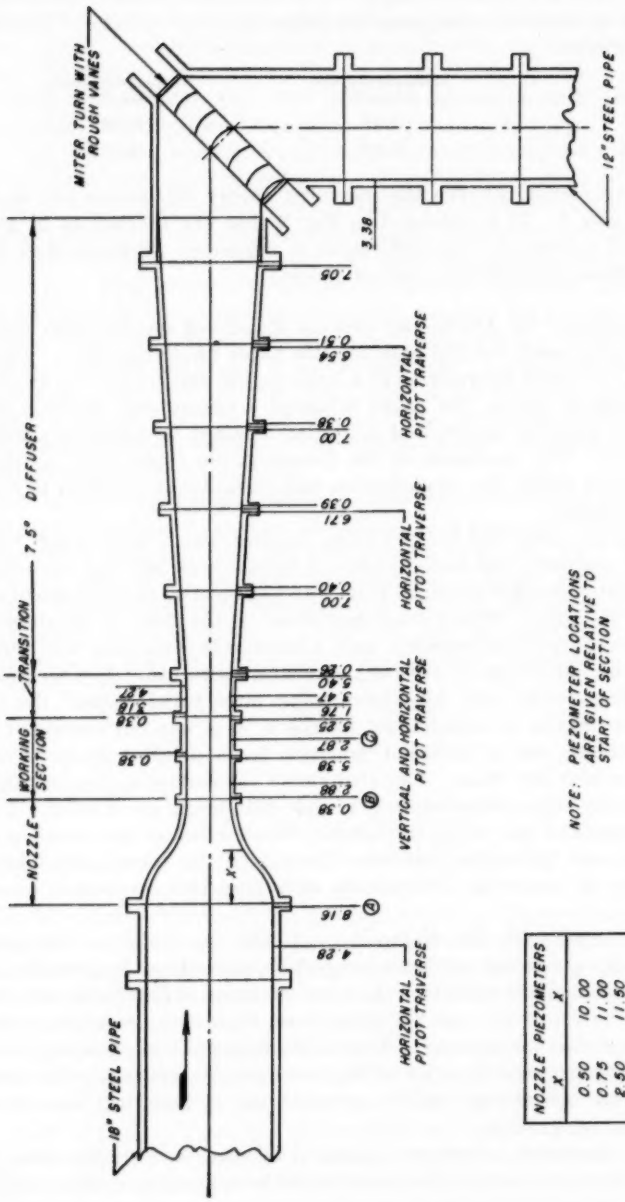

NOZZLE PIEZOMETERS X	X
0.50	10.00
0.75	11.00
2.50	11.50
3.50	12.00
5.50	12.50
7.00	13.00
8.50	

FIG. 15.—INSTRUMENTATION FOR A TEST SERIES

ity of Minnesota with great interest. The report (28) on which this paper is based included a comparison of the 5°-diffuser test made at the University of Minnesota with the summary from Fig. 6. In this case, agreement to within 0.8% at $\beta\ L/D_o$ of 40 was found. As the experimental scatter in the data (for $\beta\ L/D_o$ less than 60) was approximately 1%, it was felt to be a good check. A brief study of the 6° 40′ diffuser results presented by Mr. Olson suggests that he has not made sufficient allowance for the effective entrance length, L. In the writers' case, the actual length of straight pipe was increased 1.3 diameters to 1.5 diameters to allow for the nozzle and transition; about 1 diameter of this was for the nozzle. In the University of Minnesota tests the nozzle used was more than twice as long. The writers suggest that the effective nozzle length should have been 2.2 diameters rather than 0.5 diameter, as assumed by Mr. Olson. This changes the values of $\beta\ L/D_o$ from 7.7 and 19.8 to 19.4 and 31.0, respectively, and reduces the divergence of the University of Minnesota data from the trend shown in Fig. 6 to 1½%. Whether the excess of this divergence over the scatter of the experimental data is caused by a higher wall roughness, a slightly different definition of the pressure difference Δp, or a nonconservative estimate of the effective pipe length of the nozzle is difficult to determine. However, it is emphasized that care and judgment must be exercised in properly estimating the effective entrance length of pipe, and that a velocity traverse in this section would be most useful.

In any hydraulic phenomena, in which both the upstream and downstream flow conditions affect the element, there are a number of alternative methods of defining a figure of merit. Of the various "efficiencies" only one can truly be called an efficiency—this is the energy efficiency. The other terms are only measures of the diffuser's effectiveness according to some standard. The writers used pressure efficiency because it was the simplest possible measure of diffuser effectiveness, in so far as this efficiency refers the regained pressure to a quantity uniquely determined by the diffuser geometry. It was for this reason that the variation in this factor was correlated with other geometric terms. The suitability of any such factor as a circuit parameter is based on the needs in circuit analysis. Given the initial conditions—pressure, velocity distribution, and total energy at the start of the element, it is desired to compute the terminal conditions. The pressure efficiency, which is a function of the entrance conditions, determines the pressure at the discharge end, whereas the energy efficiency determines the losses. The discharge-velocity distribution is described by the factor α, or by the boundary-layer thickness and velocity-profile shape parameter. The only factor of importance to circuit analysis not covered in the paper is the energy change occurring downstream from the diffuser, where in straight pipe the velocity profile eventually returns to that of normal pipe flow.

The writers' objections to the conversion efficiency (Eq. 12) were based on its lack of suitability when applied to elements other than diffusers. The true energy efficiency seemed more appropriate because it is as meaningful for a straight pipe or a pipe bend as it is for a diffuser.

The writers agree with Mr. Olson concerning the importance of having the diffuser preceded by an adequate transition. For the results reported in the paper the transition was about 1 diameter long and the contour was a modified

cubic (30*a*). In other phases of the experimental water-tunnel studies other transitions were tested, including a sharp transition. Even for this extreme case, no serious effect was noted on a diffuser which was relatively safe from separation. It appears, therefore, that any curved transition is satisfactory for diffuser flow if it is gradual enough to prevent local flow separation. The chief effect of the transition is its influence on the flow upstream and its cavitation potentialities. In the case of the 48-in water-tunnel design, the 7° diffuser is preceded by a transition 1.5 diameter long.

Mr. Olson discusses the effects of a test model or other small obstruction in the straight pipe (test or working section) preceding the diffuser in the diffuser flow. The writers also studied this question, by inserting a 1-in.-diameter simulated model in a 3-diameter straight-pipe section preceding the 7.5° diffuser. The resultant pressure efficiency was 1% less than that for the bare tunnel. Velocity traverses indicated an appreciable effect, but the body wake did not interact with the wall boundary layer until an area ratio of approximately three was reached. Therefore, the chances of separation should not have been appreciably altered. Naturally, the maximum velocity in the cross section was increased and the center-line velocity was decreased over that obtained without the model.

The paper reports on research completed in 1948. Following this, many papers have appeared on turbulent boundary-layer flows, and additional detailed studies of both an analytical and experimental nature have been made. The interim conclusions reported in the paper are of value primarily to designers of diffusers similar to those tested.

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